

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.					
1. REPORT DATE (DD-MM-YYYY) 12-09-2008		2. REPORT TYPE Journal Article		3. DATES COVERED (From - To)	
4. TITLE AND SUBTITLE High-pressure freezing, crystal structure studies and Si-CF ₃ bond polarizability of trimethyl(trifluoromethyl)silane (Preprint)				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Anna Olejniczak, Andrzej Katrusiak (Faculty of Chemistry, Adam Mickiewicz University, Poland), Ashwani Vij (AFRL/RZSP)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER 23030423	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Air Force Research Laboratory (AFMC) AFRL/RZSP 10 E. Saturn Blvd. Edwards AFB CA 93524-7680				8. PERFORMING ORGANIZATION REPORT NUMBER AFRL-RZ-ED-JA-2007-481	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Air Force Research Laboratory (AFMC) AFRL/RZS 5 Pollux Drive Edwards AFB CA 93524-7048				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S NUMBER(S) AFRL-RZ-ED-JA-2007-481	
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution unlimited (PA #08440A).					
13. SUPPLEMENTARY NOTES For publication in <i>Journal of Fluorine Chemistry</i> , 129 (2008) 1090-1095.					
14. ABSTRACT Trimethyl(trifluoromethyl)silane, (CH ₃) ₃ SiCF ₃ , has been in situ pressure frozen in a diamond anvil cell and its structure determined at 0.90(5) GPa/296 K by single-crystal X-ray diffraction. The crystal is monoclinic, space group P2 ₁ /m, with the molecules lying on crystallographic mirror planes. The CH ₃ and CF ₃ groups assume the fully staggered conformation. The 14-fold coordination scheme of the molecules is similar to those in (CH ₃) ₃ SiCl polymorphs, but different from that in crystalline tetramethylsilane, (CH ₃) ₄ Si (TMS). The longest Si-C bond length of 1.943(12) Å observed in the crystal structure has been documented. The shortest intermolecular contacts in the structure of pressure-frozen CF ₃ Si(CH ₃) ₃ are observed between the hydrogen atoms, and those involving fluorine atoms are longer than sums of van der Waals' radii. These structural features explain the facile cleavage of Si-CF ₃ bond for CF ₃ group transfer in organic reactions.					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Mr. Wayne Kalliomaa
Unclassified	Unclassified	Unclassified	SAR	12	19b. TELEPHONE NUMBER (include area code) N/A

High-pressure freezing and crystal structure studies of TMSCF₃: Understanding nucleophilic -CF₃ transferring ability (Preprint)

Anna Olejniczak¹, Andrzej Katrusiak^{1*} and Ashwani Vij^{2*}

¹Faculty of Crystal Chemistry, Adam Mickiewicz University, Grunwaldzka 6, 60-780 Poznan, Poland, e-mail: katran@amu.edu.pl;

²AFRL/RZSP, Edwards Air Force Base, 10 E. Saturn Blvd., Bldg. 8451, CA 93524, USA, e-mail: ashwani.vij@edwards.af.mil

Abstract

Trimethyl(trifluoromethyl)silane, (CH₃)₃SiCF₃, has been *in-situ* pressure-frozen in a diamond anvil cell and its structure determined at 0.9 GPa/296 K by single-crystal X-ray diffraction. The crystal is monoclinic, space group P2₁/m with molecules lying on the crystallographic mirror plane. The CH₃ and CF₃ groups assume the fully staggered conformation. The 14-fold coordination scheme of the molecules is similar to those in (CH₃)₃SiCl polymorphs, but different from that in crystalline tetramethylsilane (CH₃)₄Si (TMS). The Si-CF₃ bond is slightly longer than Si-CH₃ bond and the shortest intermolecular contacts in the structure of pressure-frozen CF₃Si(CH₃)₃ are observed between fluorine and hydrogen atoms. These structural features explain the facile cleavage of Si-CF₃ bond for CF₃ group transfer in organic reactions.

Introduction

Silanes are important chemical compounds, owing to their physical and chemical properties. They are widely applied, for example: in dentistry, medicine, construction technologies, synthesis, as adhesion promoters, coupling, cross-linking or dispersing agents and surface modifiers.¹ Trimethyl(trifluoromethyl)silane can be considered as a derivative of tetramethylsilane (TMS) where three hydrogen atoms of a methyl group are replaced by fluorine atoms. Generally, this kind of substitution changes physical and chemical properties of compounds considerably as a result of intermolecular interaction. Consequently, fluorinated compounds have markedly different properties than their non-fluorinated counterparts and thus find wide ranging applications from medicine to technology.² Trimethyl(trifluoromethyl)silane, first synthesized in 1984 by Ruppert³ and commonly known as Ruppert's reagent, is used for syntheses of perfluorinated compounds and for introducing of a trifluoromethyl group by nucleophilic reaction.⁴⁻⁸ For these reasons the structural

information about $(\text{CH}_3)_3\text{SiCF}_3$ are of particular interests and studies by gas phase electron diffraction, microwave spectroscopy and quantum chemical calculations were performed.⁹ The principal interest for these studies focused on the difference between Si–CF₃ and Si–CH₃ bond lengths and in the intermolecular interactions. Vibrational-spectroscopy studies on CF₃-silanes showed that the substitution of H-atoms with F-atoms lengthens and weakens the Si–CF₃ bond,^{10,11} which results from the electronegative F-atoms withdrawing the electrons from C and Si-atoms, causing electrostatic repulsion of their positive net-atomic charges, and a deficiency in the binding σ -electron pair. However, to the best of our knowledge, no solid state/crystal structure of $(\text{CH}_3)_3\text{SiCF}_3$ as a result of x-ray or neutron powder diffraction results has been reported so far. It was also established most recently, that the $\text{Si}(\text{CH}_3)_4$ (*i.e.* tetramethylsilane, TMS) molecules in the crystalline state are distorted from the fully-staggered conformation.¹² That result is consistent with previous electron-diffraction measurements for TMS vapor, and it was proposed that the twisted TMS conformation releases the intramolecular strains of interacting H-atoms.¹³ Thus the aim of this study was to provide the molecular dimensions and conformation of $(\text{CH}_3)_3\text{SiCF}_3$, and also to investigate the influence of the fluorine atoms and the molecule polarization for the intermolecular interactions and crystal packing. Further, it is also important to understand why this molecule does not spontaneously decompose to form a more stable molecule, $(\text{CH}_3)_3\text{SiF}$, with an explosive formation of difluorocarbene.

Experimental

Trimethyl(trifluoromethyl)silane has been crystallized in a modified Merrill-Bassett¹⁴ diamond anvil cell (DAC). Because of the relatively low boiling point (327-328 K),¹⁵ the liquid and the DAC were cooled with solid CO₂ for loading the sample. It crystallized at 0.2 GPa and then the high-pressure chamber was squeezed till its whole chamber volume was filled by the polycrystalline sample. To ensure stable conditions for the diffraction measurements, pressure was increased to 0.9 GPa, and then the DAC was heated. A single crystal was grown isohorically from one seed crystal left in the melt sample at 473 K, followed by slowly cooling the sample to 296 K. During the first stage of cooling many defects appeared on the crystal surface (Fig. 1 a-b). Therefore, the crystal was kept at 333 K for 2 hours until the process of self-healing eliminated all defects observed in crystal morphology (Fig. 1c-e). After cooling the DAC to room temperature five days passed before the diffraction data were measured.

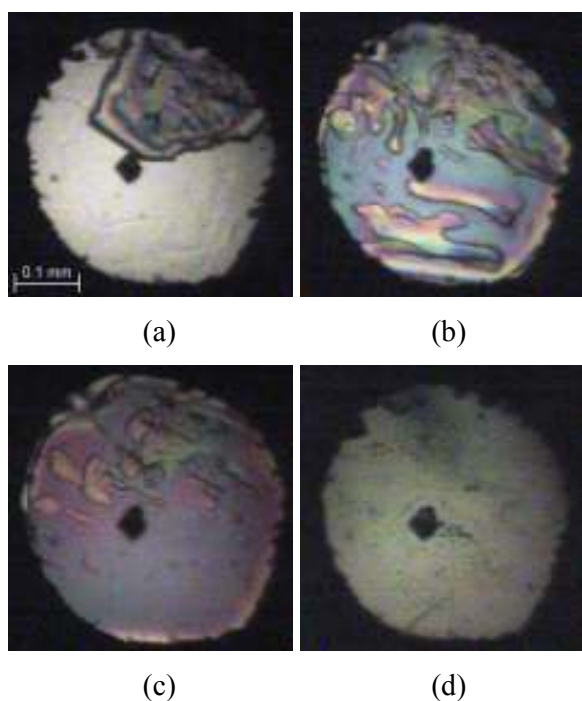


Figure 1. Isochoric-growth stages of the $(\text{CH}_3)_3\text{SiCF}_3$ single crystal: (a) distorted morphology of a small single crystal at 453 K; (b) the crystal at 333 K with its faces highly irregular; (c) the same crystal after 1 hour at 333 K; and (d) the crystal at room temperature and 0.9 GPa. The small ruby chip for pressure calibration is placed close to the centre of the DAC.

Pressure in the DAC was calibrated by ruby-fluorescence method,^{16,17} using a Betsa PRL spectrometer, with an accuracy of 0.05 GPa. The single-crystal X-ray diffraction study was carried out with a KUMA KM4-CCD diffractometer. The CrysAlis version 1.171.24 software¹⁸ was used for the data collections¹⁹ and the preliminary reduction of the data. After correcting the intensities for the effects of DAC absorption, sample shadowing by the gasket, and the sample absorption,^{20,21} the diamond reflections were eliminated. The systematic absences and statistics of reflections intensities indicated that the crystal is monoclinic in space group $P2_1/m$. The structure was solved straightforwardly by direct methods,²² and refined by full-matrix least-squares.²³ Anisotropic temperature factors were applied for all non-hydrogen atoms. The crystal data and the structure refinement details are listed in Table 1. Structural drawings were prepared using the X-Seed interface of POV-Ray.^{24,25}

Table 1. Selected crystal data and details of structure refinement for (CH₃)₃SiCF₃.

Formula	(CH ₃) ₃ SiCF ₃
Pressure (GPa)	0.90(5)
Temperature (K)	296(2)
Formula weight	142.20
Wavelength (Å)	0.71073
Crystal system	Monoclinic
Space group	P2 ₁ /m
Unit cell dimensions (Å, °)	<i>a</i> = 5.9737(12) <i>b</i> = 9.4228(19) <i>c</i> = 6.3231(13) <i>β</i> = 105.30(3)
Volume (Å ³)	343.31(12)
<i>Z</i>	2
Calculated density (g/cm ³)	1.376
Absorption coefficient (mm ⁻¹)	0.301
<i>F</i> (000)	148
Crystal diameter/height (mm)	0.38/0.20
<i>θ</i> -range for data collection (°)	3.98 to 29.43
Min./max. indices <i>h</i> , <i>k</i> , <i>l</i>	-5/5, -12/12, -6/6
Reflect. collected/ unique (<i>R</i> _{int})	2543/378 (0.0733)
Completeness (%) (to <i>θ</i> _{max})	37.5 (to 29.43°)
Refinement method:	Full-matrix least-squares on <i>F</i> ²
Data/restraints/parameters	378/2/48
Goodness-of-fit on <i>F</i> ²	1.092
Final <i>R</i> ₁ / <i>wR</i> ₂ (<i>I</i> > 2σ ₁ <i>I</i>)	0.0600/0.1391
<i>R</i> ₁ / <i>wR</i> ₂ (all data)	0.0709/0.1464
Weighting scheme	$w=1/(\sigma^2(F_o^2)+(0.0724*P)^2+0.17*P)$, where $P=(\text{Max}(F_o^2,0)+2*F_c^2)/3$
Largest diff. peak and hole (e.Å ⁻³)	0.440/-0.380

Results and discussion

Molecular geometry

In the pressure-frozen $(\text{CH}_3)_3\text{SiCF}_3$ structure atoms Si1, C1, C2, F2 and H2 of the molecule are located on a crystallographic mirror plane of space group $P2_1/m$ (Figure 2).

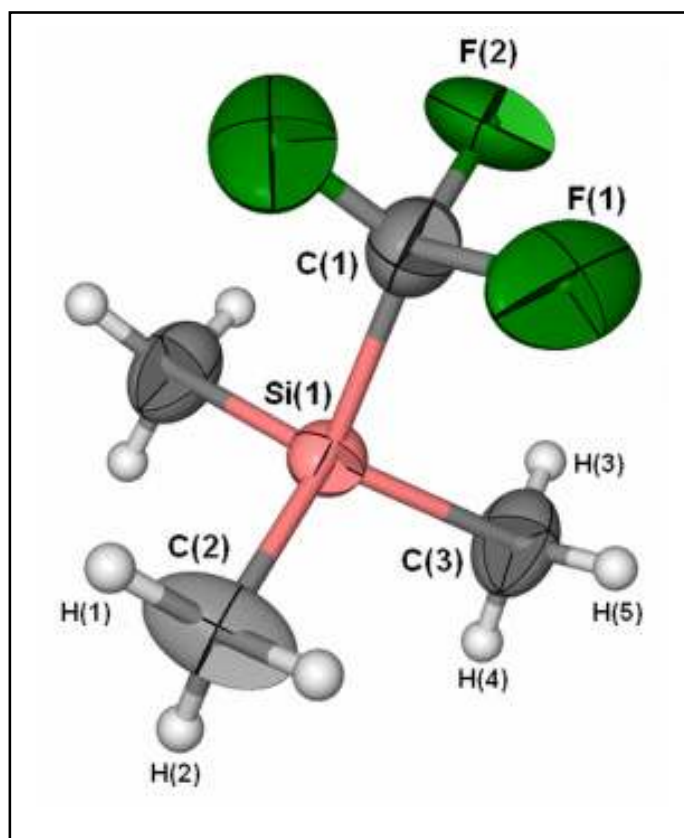


Figure 2. The molecule of $(\text{CH}_3)_3\text{SiCF}_3$ at 0.9 GPa and 296 K. Only the symmetry-independent atoms have been labeled in this drawing.

The Si-atom is in a tetrahedral environment and is bonded to one CF_3 group and three CH_3 groups. However, the C–Si–C angles are significantly distorted from the ideal tetrahedral value, and range from $102.1(7)^\circ$ to $113.9(3)^\circ$ (Table 2). It is noteworthy, that the valency angles C–Si–C involving atom C(1)F₃ are considerably smaller than the C–Si–C valency angles between the methyl groups, which rules out the possibility of intramolecular steric hindrances between F and H atoms. The lengths of three Si–CH₃ bonds (two of which are symmetry independent) are consistent within errors. The methyl group (C2) lying on the mirror plane is slightly longer at $1.862(11)$ Å compared to the one with C3 located at a general position $1.848(6)$, whereas the Si–CF₃ bond is by nearly 0.1 Å longer at $1.943(12)$ Å. All these values agree

well with the electron diffraction in the gaseous phase and by theoretical calculations for the isolated molecule.⁹ The largest differences between calculated and experimental dimensions are in the C–F bonds lengths and in CF₃–Si–CF₃ and F–C–F angles (Table 2). As predicted, the Si–C bond length depends on its intramolecular environment, and in the X–Si–(CH₃)₃ molecules (X stands for H, Cl, F, I, CH₃, CF₃) it shortens with increasing electronegativity of the X-group.⁹ The theoretical studies on structures of some silanes showed that this is (CH₃)₃SiCF₃ where Si–C bond is the longest.⁹ This is consistent with the tendency of (CH₃)₃SiCF₃ for the -CF₃ group donation.

The molecular conformation of (CH₃)₃SiCF₃ was also investigated theoretically and the potential energy barrier hindering the internal rotation of all methyl groups was calculated to be 5.71 kJ/mol.⁹ The staggered positions for the CH₃ and CF₃-groups were chosen for optimizing geometry in quantum chemical calculations. In the crystal structure the ideal staggered conformation is imposed by symmetry for groups C(1)F₃ and C(2)H₃. However, the C(3)H₃ methyl groups are not restricted by symmetry to rotate, and a deviation of 8(4)° from the fully staggered conformation has been observed for C(3)H₃. This deviation of C(3)H₃ is small (and statistically insignificant) and may also result from the distorted tetrahedral geometry of the (CH₃)₃SiCF₃ molecule and its intermolecular interactions.

Table 2. Bond lengths (Å) and angles (°) for (CH₃)₃SiCF₃ determined by electron diffraction⁹ and in this study (symmetry codes: i = x, -y+½, z)

	Electron diffraction ⁹	X-ray diffraction
Si–CH ₃	1.862(3)	1.848(6) Si(1)–C(3) 1.862(11) Si(1)–C(2)
Si–CF ₃	1.942(5)	1.943(12) Si(1)–C(1)
C–F	1.355(2)	1.296(9) C(1)–F(1) 1.403(9) C(1)–F(2)
CH ₃ –Si–CH ₃ ¹	Not given	111.1(5) C(3)–Si(1)–C(3) ¹ 113.9(3) C(3)–Si(1)–C(2)
CF ₃ –Si–CH ₃ ¹	106.0(5)	102.1(7) C(1)–Si(1)–C(2) 107.5(3) C(1)–Si(1)–C(3)
F–C–F ¹	106.5(2)	111.8(12) F(1)–C(1)–F(1) ¹ 103.6(4) F(1)–C(1)–F(2)

Intermolecular interactions and molecular packing

Despite high-pressure conditions, almost all intermolecular distances in the structure of $(\text{CH}_3)_3\text{SiCF}_3$ are longer than sums of tabulated values of van der Waals radii of the closest atoms²⁶. The shortest distances between F-atoms are of 3.014(7) Å, the shortest $\text{F}\cdots\text{H}$ contacts are of 2.798 Å, and 2.348 Å between the closest H-atoms. The shortest $\text{H}\cdots\text{H}$ contacts arrange molecules into [100] chains and the molecules with the shortest $\text{F}\cdots\text{F}$ and $\text{F}\cdots\text{H}$ distances run along the [010] direction. All these contacts arrange the molecules into sheets along planes (100) in the crystal lattice (Fig. 3).

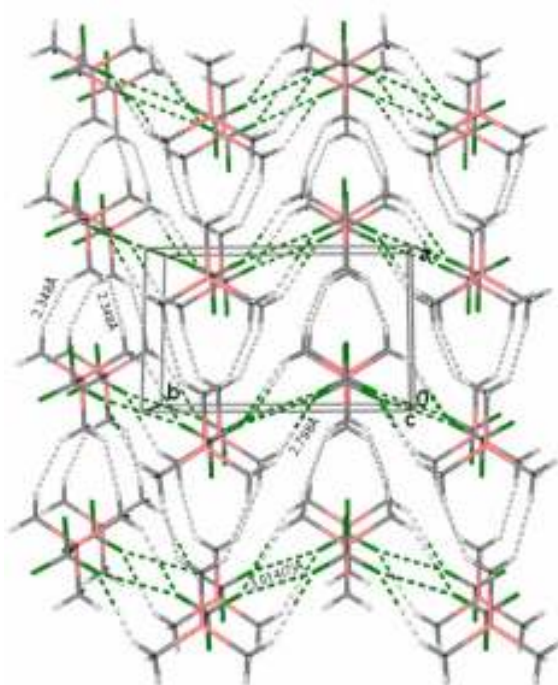


Figure 3. The molecular packing of $(\text{CH}_3)_3\text{SiCF}_3$ with the shortest $\text{H}\cdots\text{H}$, $\text{F}\cdots\text{H}$ and $\text{F}\cdots\text{F}$ contacts indicated as dashed lines.

The regions and directions of intermolecular contacts in $(\text{CH}_3)_3\text{SiCF}_3$ are mapped onto the molecular Hirshfeld surface^{27,28,29} in Fig. 4. It confirms that the shortest contacts in this structure involve the hydrogen atoms (red spots on the Hirshfeld surfaces), and that each CH_3 group fits between two other CH_3 groups of the neighboring molecules. Each molecule has four closest neighbors forming contacts $\text{H}\cdots\text{H}$ and $\text{H}\cdots\text{F}$.

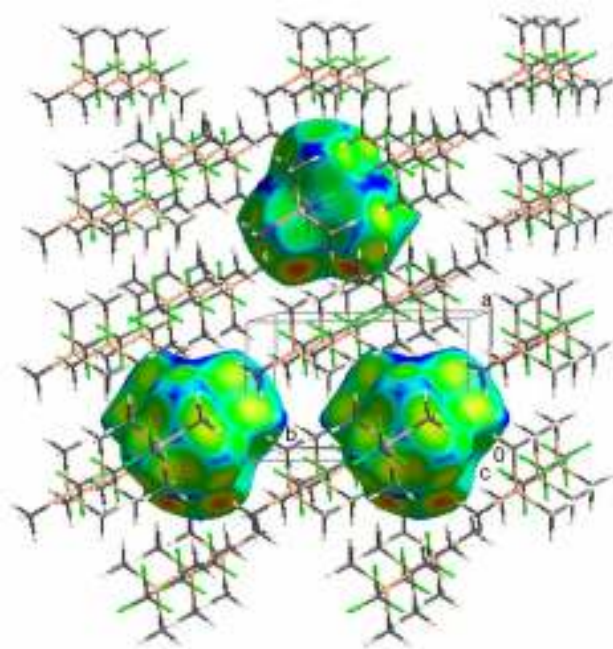


Figure 4. The intermolecular interactions represented by a color scale on the Hirshfeld surface.^{27,28,29} The property mapped onto the surface is the normalized contact distance (intermolecular contacts closer than the sum of their van der Waals radii are highlighted in red on the d_{norm} surface, longer contacts are blue, and contacts around this sum are white).

With respect to the distances to the molecular centers (associated with the Si atom in this discussion), the crystal structure corresponds to the close-packing arrangement of ideal spheres, with the coordination number of 14. The Si...Si distances are 5.8896(18), 5.8896(18), 5.9737(12), 5.9737(12), 6.216(2), 6.216(2), 6.3231(13), 6.3231(13), 6.336(4), 6.336(4), 7.288(5), 7.288(5), 7.466(3) and 7.466(3) Å within this 14-fold coordination scheme. The 12-fold coordination number was indicated as favored for molecular crystals by Kitajgorodski,³⁰ but more recent survey based on the Cambridge Crystallographic Database revealed that the 14-fold coordination may be more frequent for molecular crystals.³¹

The $(\text{CH}_3)_3\text{SiCF}_3$ crystal is isostructural with low-temperature $(\text{CH}_3)_3\text{SiCl}$ α -phase³² as both these structures are monoclinic, space group $P2_1/m$. The largest differences in unit-cell dimensions are, for the b parameter 1.69 Å longer and the β angle is 14.5° larger in $(\text{CH}_3)_3\text{SiCF}_3$ than in $(\text{CH}_3)_3\text{SiCl}$, the molecular packing is similar. Gajda *et al.*³³ established, that in low-temperature phase α and high-pressure phase β of $(\text{CH}_3)_3\text{SiCl}$ the molecules are arranged head to tail in the manner avoiding short Cl...Cl contacts. Likewise, there are no short contacts between CF_3 groups in the high-pressure $(\text{CH}_3)_3\text{SiCF}_3$ phase. The patterns of

these molecules in $(\text{CH}_3)_3\text{SiCl}$ and in $(\text{CH}_3)_3\text{SiCF}_3$ crystals, where $\text{Cl}\cdots\text{Cl}$ and $\text{F}\cdots\text{F}$ contacts are the shortest, are presented in Figure 5. Owing to the molecular geometry intermolecular contacts of the F-atoms are closer and those of the Cl-atoms are more distant in $(\text{CH}_3)_3\text{SiCF}_3$ and $(\text{CH}_3)_3\text{SiCl}$, respectively. In this respect the behavior of the halogens, or their role in the formation of the crystal structures can be described as halophobic, in accordance with the observation of other structures of halogenated compounds by Grineva & Zorkii.^{34,35}

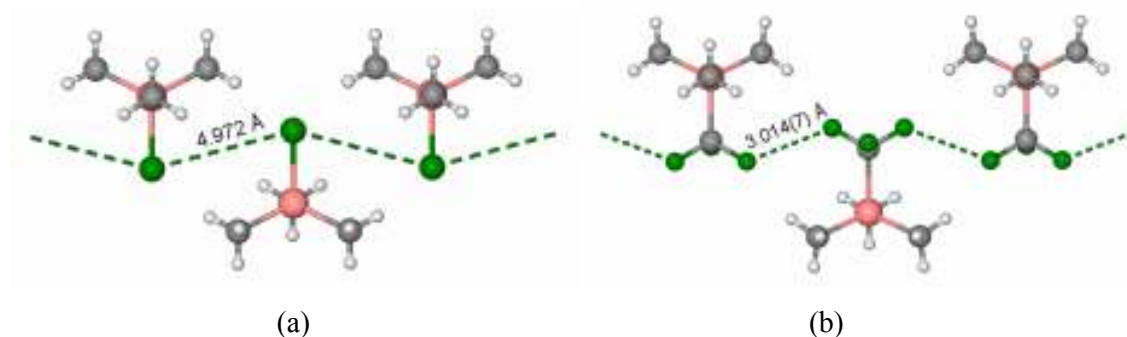


Figure 5. Patterns of molecules with the shortest $\text{Cl}\cdots\text{Cl}$ distance in $(\text{CH}_3)_3\text{SiCl}$ –phase α (a), and the shortest $\text{F}\cdots\text{F}$ distance in $(\text{CH}_3)_3\text{SiCF}_3$ (b).

These repulsive halogen \cdots halogen interactions are reflected in the shapes of coordination schemes presented in Figure 6. The molecules of $(\text{CH}_3)_3\text{SiCF}_3$ and $(\text{CH}_3)_3\text{SiCl}$ in phases α and β are similarly 14-fold coordinated. Despite similar molecular shape, the $(\text{CH}_3)_3\text{SiCF}_3$ structure is considerably different from that of $(\text{CH}_3)_4\text{Si}$, which is cubic, space group $Pa\bar{3}$, with the molecules located on C_3 axes and 13-fold coordinated¹². The common feature of all the silanes investigated is weak intermolecular interactions.

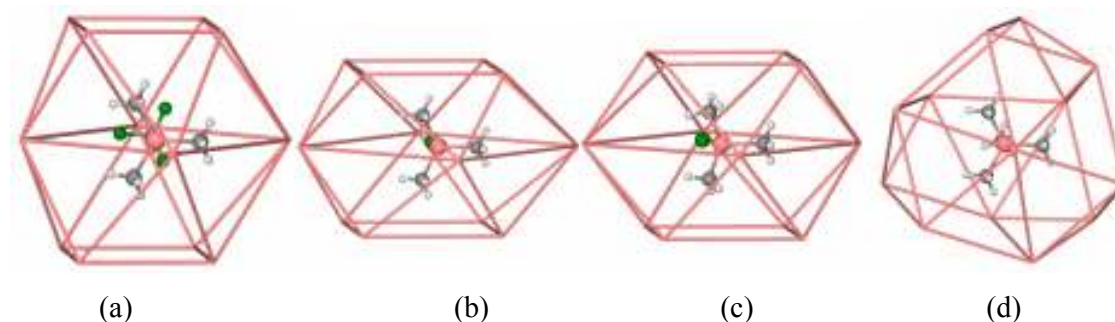


Figure 6. The coordination schemes of $(\text{CH}_3)_3\text{SiCF}_3$ (a); $(\text{CH}_3)_3\text{SiCl}$, phase α (b); $(\text{CH}_3)_3\text{SiCl}$, phase β (c); and $(\text{CH}_3)_4\text{Si}$ (d). The vertices of the coordination schemes represent the Si atoms closer than 8 Å to the central Si atom.

Conclusions

This study on the crystal structure of trimethyl(trifluoromethyl)silane confirmed that the Si–CF₃ bond is longer and weaker than the Si–CH₃ bonds. It has been confirmed that there are no strong intermolecular interactions in $(\text{CH}_3)_3\text{SiCF}_3$. This result supports the trifluoromethylating nature of this reagent as the CF₃ group is easily transferred without decomposing to form $(\text{CH}_3)_3\text{SiF}$ and :CF₂ (difluorocarbene). Also, the structure of $(\text{CH}_3)_3\text{SiCF}_3$ isostructural with $(\text{CH}_3)_3\text{SiCl}$ in α -phase seems to confirm that the H···H interactions and the similar molecular shape are essential facts for the molecular coordination scheme, similar to those in both α - and β -phases of $(\text{CH}_3)_3\text{SiCl}$. The different coordination scheme in $(\text{CH}_3)_4\text{Si}$ may be due to the presence of an additional methyl group in this molecule. However, the common feature of all of the silanes investigated is the absence of strong intermolecular interactions.^{12,32,33,36}

References

- (1) Auner, N.; Weis, J. *Organosilicon Chemistry: From Molecules to Materials*; Wiley-VCH, Weinheim, 1994.
- (2) Kirsch, P. *Modern Fluoroorganic Chemistry*; Wiley-VCH, Weinheim, 2004.
- (3) Ruppert, I.; Schlich, K.; Volbach, W. *Tetrahedron Lett.* 1984, 25, 2195.
- (4) Surya Prakash, G. K.; Yudin, A. K. *Chem. Rev.* 1997, 97, 757.
- (5) Li, G.; Chen, Y.; Missert, J. R.; Rungta, A.; Dougherty, T. J.; Grossman, Z. D.; Pandey, R. K. *J. Chem. Soc., Perkin Trans.* 1999, 1, 1785.
- (6) Blazejewski, J.-C.; Anselmi, E.; Wilmshurt, M. P. *Tetrahedron Lett.* 1999, 40, 5745.
- (7) Surya Prakash, G. K.; Mandal, M. J. *Fluor. Chem.* 2001, 112, 123.
- (8) Kirij, N. V.; Yagupolskii, Y. L.; Petukh, N. V.; Tyrre, W.; Naumann, D. *Tetrahedron Lett.* 2001, 42, 8181.
- (9) Klatte, K.; Christen, D.; Merke, I.; Stahl, W.; Oberhammer, H. *J. Phys. Chem. A* 2005, 109, 8438.
- (10) Beckers, H.; Bürger, H.; Eujen, R. *J. Mol. Struct.* 1986, 140, 281.
- (11) Eujen, R. *Spectrochimica Acta* 1987, 43A, 1165.

- (12) Gajda, R.; Katrusiak, A. – Cryst. Growth Des.: in print.
- (13) Campanelli, A. R.; Ramondo, F.; Domenicano, A.; Hargittai, I. Struct. Chem. 2000, 11, 155.
- (14) Merrill, L.; Bassett, W. A. Rev. Sci. Instrum. 1974, 45, 290.
- (15) Sigma–Aldrich. Aldrich Advancing Science 2005–2006 Poland, Sigma–Aldrich Corporation, Poznan, Poland, 2005, pp. 2397.
- (16) Piermarini, G. J.; Mighell, A. D.; Weir, C. E.; Block, S. Science 1969, 165, 1250.
- (17) Mao, H. K.; Xu, J.; Bell, P. M. J. Geophys. Res. 1985, 91, 4673.
- (18) Oxford Diffraction Limited. User Manual Xcalibur series Single Crystal Diffractometers, Version 1.3. Oxford Diffraction Poland, Wrocław, 2002.
- (19) Budzianowski, A.; Katrusiak, A. In High-Pressure Crystallography; Katrusiak, A.; McMillan, P. F., Eds.; Kluwer Academic Publisher, Dordrecht, 2004, Vol. 140, Chapter 1, pp 101–112.
- (20) Katrusiak, A. REDSHABS. Program for the correcting reflections intensities for DAC absorption, gasket shadowing and sample crystal absorption. Adam Mickiewicz University, Poznań, 2003.
- (21) Katrusiak, A. Z. Kristallogr. 2004, 219, 461.
- (22) Sheldrick, G. M. Acta Cryst A. 1990, 46, 467.
- (23) Sheldrick, G.M. The SHELX-97 manual. Univ. of Göttingen, Germany, 1997.
- (24) Barbour, L. J. J. Supramol. Chem. 2001, 1, 189.
- (25) Persistence of Vision Pty. Ltd. Persistence of Vision (TM) Raytracer, Version 2.6. Williamstown, Victoria, Australia, 2004.
- (26) Batsanov, S. S. Inorg. Matt. 2001, 37, 1031.
- (27) McKinnon, J. J.; Spackman, M. A.; Mitchell, A. S. Acta Cryst. B 2004, 60, 627.
- (28) Wolff, S. K.; Grimwood, D. J.; McKinnon, J. J.; Jayatilaka, D.; Spackman, M. A. CrystalExplorer, Version 1.5.0, University of Western Australia, 2005.
- (29) Dziubek, K. F.; Katrusiak, A. J. Phys. Chem. B 2004, 108, 19089.
- (30) Kitajgorodski, A. I. (1976). Krysztaly molekularne. Warsaw: PWN (In Polish). pp 29-31.
- (31) Peresypkina, E. V.; Blatov, V. A. Acta Cryst. Sec.B 2000 B56, 501.
- (32) Buschmann, J.; Lentz, D.; Luger, P.; Röttger, M. Acta Cryst., Sect.C 2000, C56, 121.
- (33) Gajda, R.; Dziubek, K.; Katrusiak, A. Acta Cryst., Sect.B 2006, B62, 86.
- (34) Grineva, O. V.; Zorkii, P. M. J. Stuct. Chem. 2001, 42, 16.
- (35) Grineva, O. V.; Zorkii, P. M. J. Stuct. Chem. 2002, 43, 994.
- (36) Dinnebier, R. E.; Carlson, S.; van Smaalen, S. Acta Cryst., Sect. B 2000, B56, 310.